Flexible, Low-Mass Devices and Mechanisms Actuated by Electroactive Polymers (EAP)

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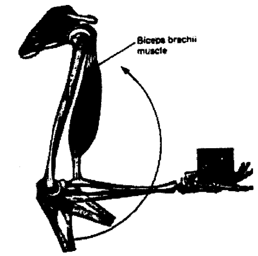
Miniature, lightweight, low-cost actuators that consume low-power are being developed using Electroactive polymers (EAP). Two polymer actuator types are being developed inducing large bending and longitudinal actuation strains. These actuators are enabling new mechanisms and devices that are fracture tolerant. Several EAP driven mechanisms, which emulate human hand, were developed including a gripper, manipulator arm and surface wiper. The manipulator arm was made of a composite rod with a lifting actuator consisting of a scrolled rope that is activated longitudinally by an electrostatic field. A gripper was made to serve as an end effector and it consisted of multiple bending EAP fingers for grabbing and holding such objects as rocks. An EAP surface wiper was developed to operate like a human finger and to demonstrate the potential to remove dust from optical and IR windows as well as solar cells. These EAP driven devices are taking advantage of the large actuation displacement of these materials for applications that have limited requirement for actuation force capability.

Tests were made at T=-100oC and P~1 Torr, which are below Mars conditions, and the results show that the bending actuator was still responding with a significant actuation displacement.



Flexible, low-mass devices and mechanisms actuated by electroactive polymers (EAP)

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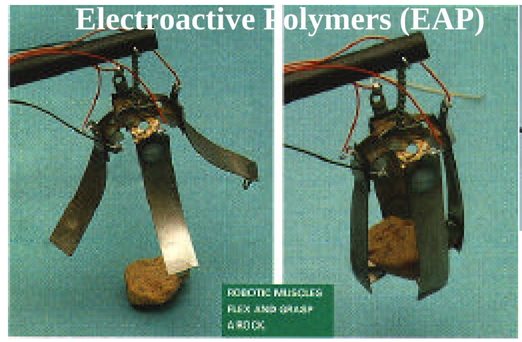
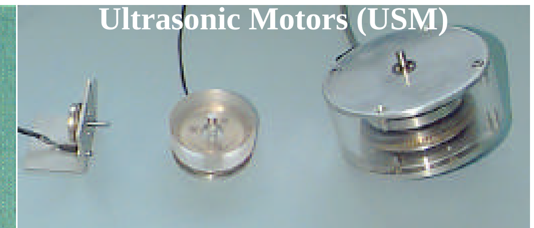
NASA/JPL WORKSHOP ON BIOMORPHIC EXPLORERS FOR FUTURE MISSIONS, held at JPL, August 19-20, 1998

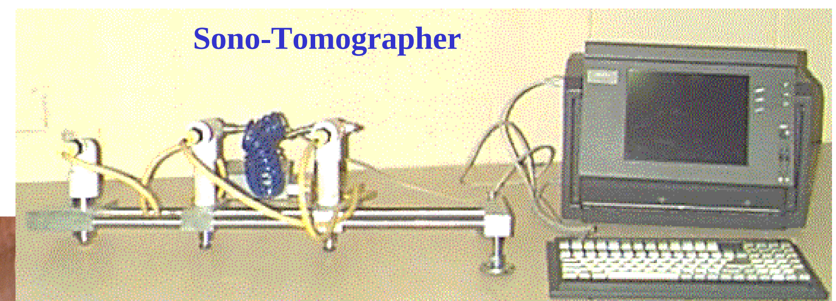
NDEAA addressing planetary exploration needs

- Actuators: EAP, FMPUL and ultrasonic motors
- Properties sensors: Leaky Lamb Waves (LLW) and Sono-Tomographer (NGPS)
- Robotics: MACS





Discover Magazine, Aug. 98, p.33



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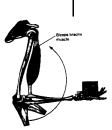
COMPARISON BETWEEN EAP AND WIDELY USED TRANSDUCING ACTUATORS

Property	EAP	EAC (Piezoceramics)	SMA
Actuation displacement	>10%	0.1 - 0.3 %	<8% short fatigue life
Force (MPa)	0.1 - 3	30-40	about 700
Reaction speed	µsec to sec	µsec to sec	sec to min
Density	1- 2.5 g/cc	6-8 g/cc	5 - 6 g/cc
Drive voltage	4 - 7 V	50 - 800 V	NA
Power consumption	m-watts	watts	watts
Fracture toughness	resilient, elastic	fragile	elastic



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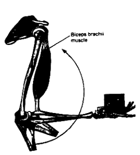
BACKGROUND

- Emulating biological muscles enables unique locomotion capabilities
- Electroactive polymers (EAP) are emerging with capability that mimic muscles.
- EAP actuators can be made miniature, low mass, inexpensive and consume low power.

TECHNOLOGY STATUS

- Bending and longitudinal EAP actuators are developed.
- Demonstrated unique applications: surface wiper, gripper and arm lifter.
- Changed the paradigm about robotics construction and actuation - EAP materials can serve simultaneously as a structural element, actuator and end-effector.
- Seeking transition to multi-actuation locomotion insect-like robotic colonies that emulate ants.



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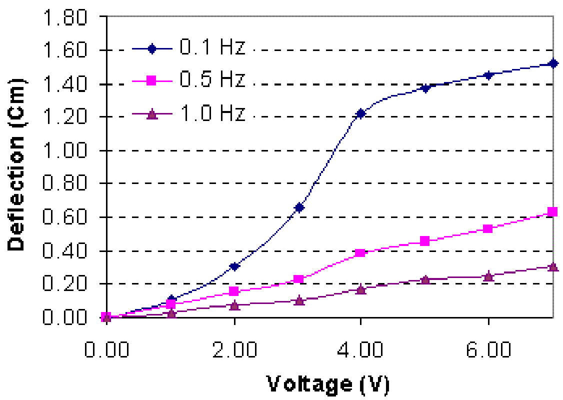
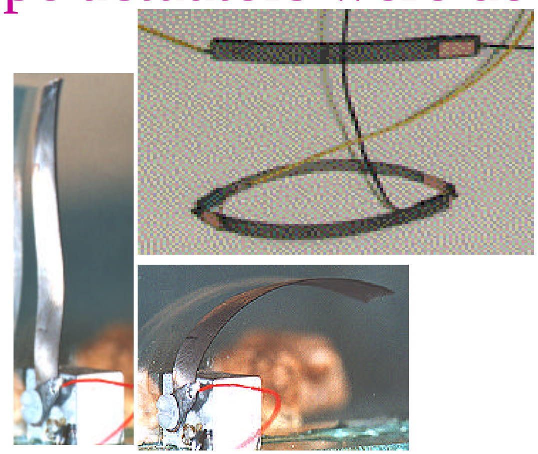
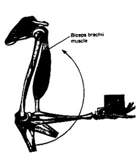
TECHNOLOGY DESCRIPTION

A bending and stretching type actuators were developed





Ion-exchange Polymer membrane Metallic Composite (IPMC) can bend by over 90^{o} under ~3-4V and ~30-50-mW.



31-mm wide, 50-µm thick Electrostatically stricted polymer (ESSP) film extending over 12%

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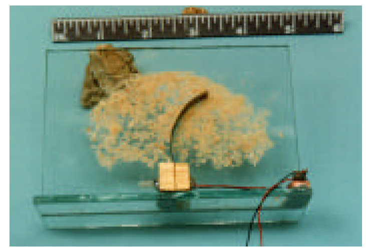
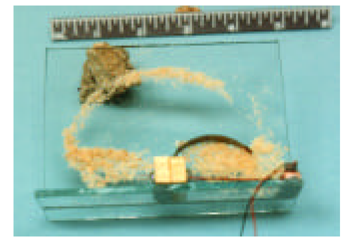
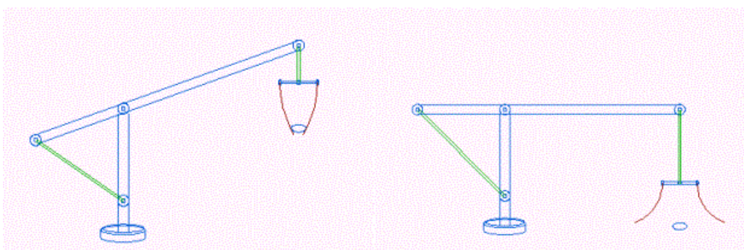
EAP POTENTIAL APPLICATIONS

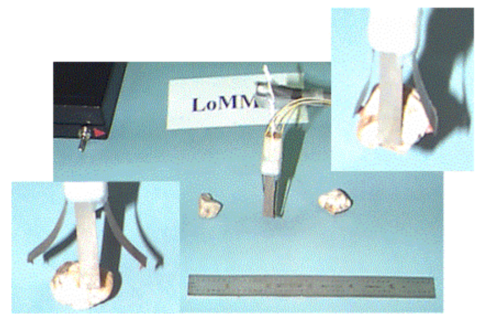
Use of bending EAP

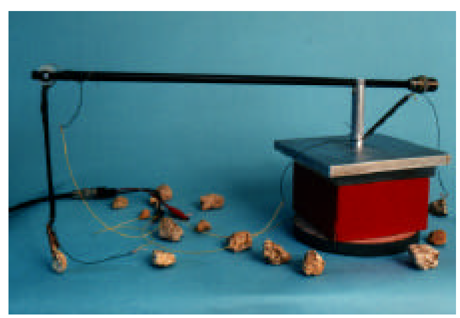


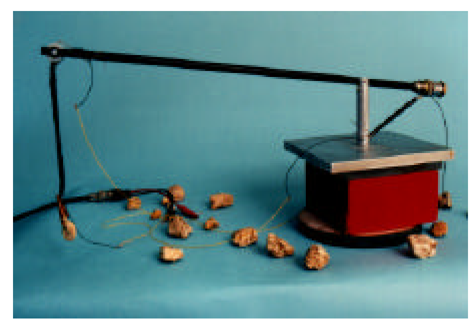


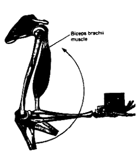


Use of stretching EAP









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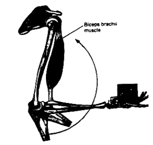
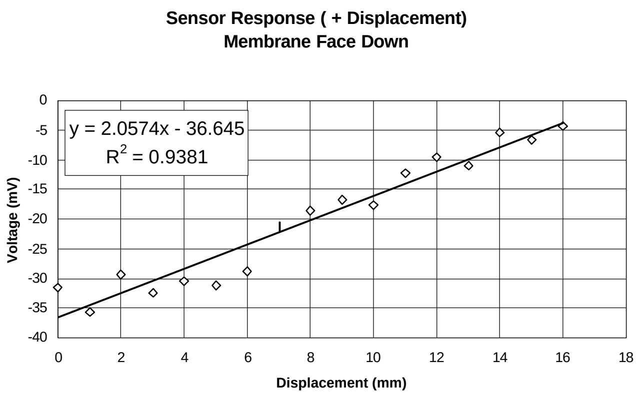
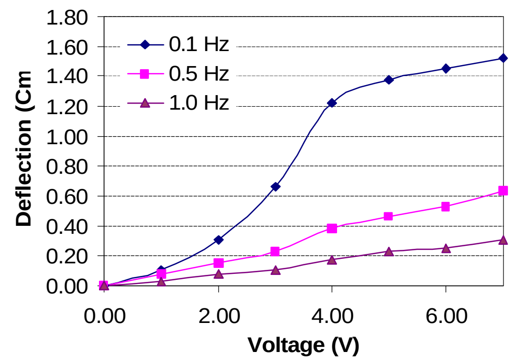
EAP BENDING ACTUATOR/SENSOR

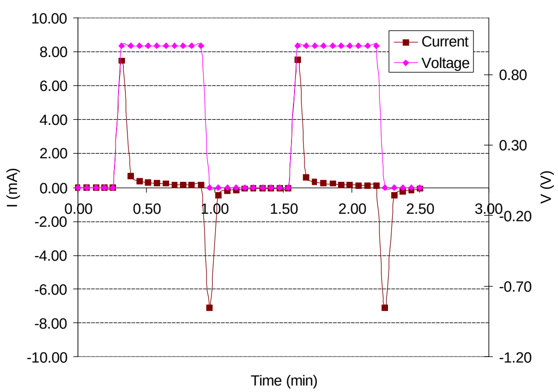




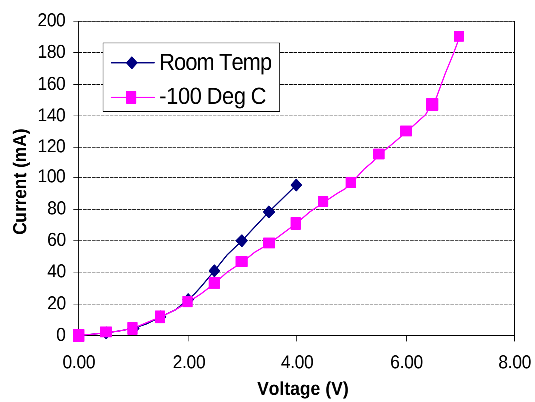
Sensor



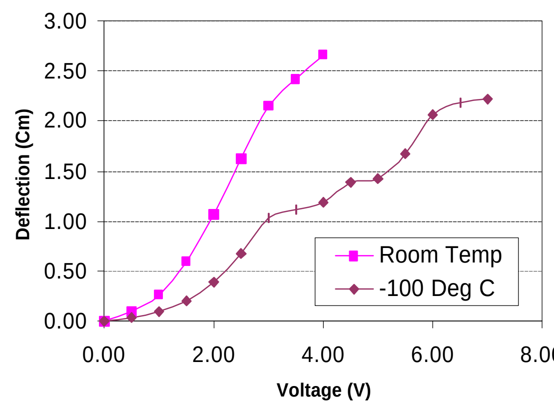
Actuator



Charging capability



Higher resistance at Low Temp



Response at Cryovac

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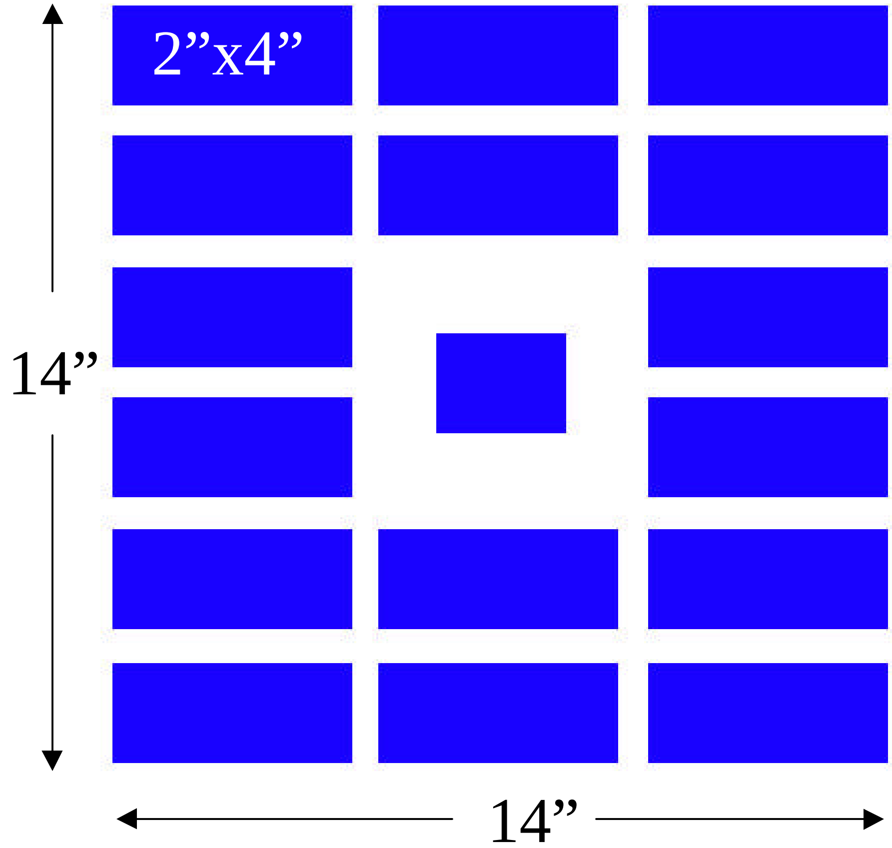
Solar cells layout on the NanoRover



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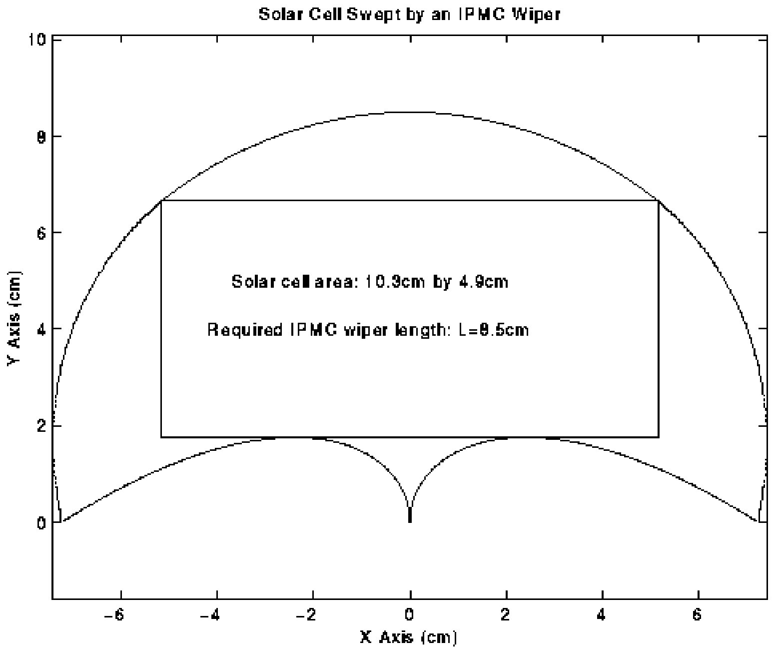
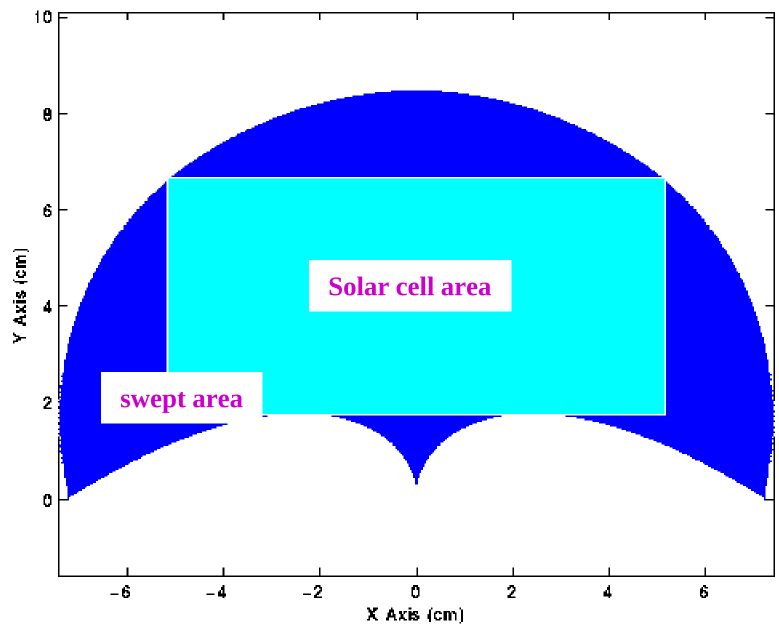
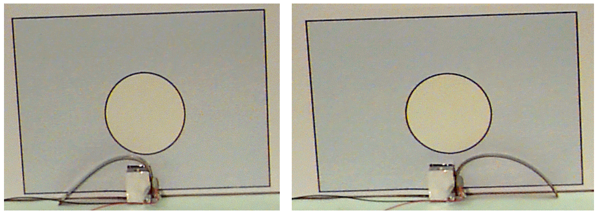
Surface wiper using bending EAP

Using best fit wiper curving characteristics for a 103mmX49mm area





Actual bending



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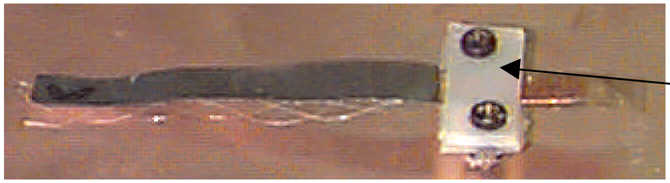
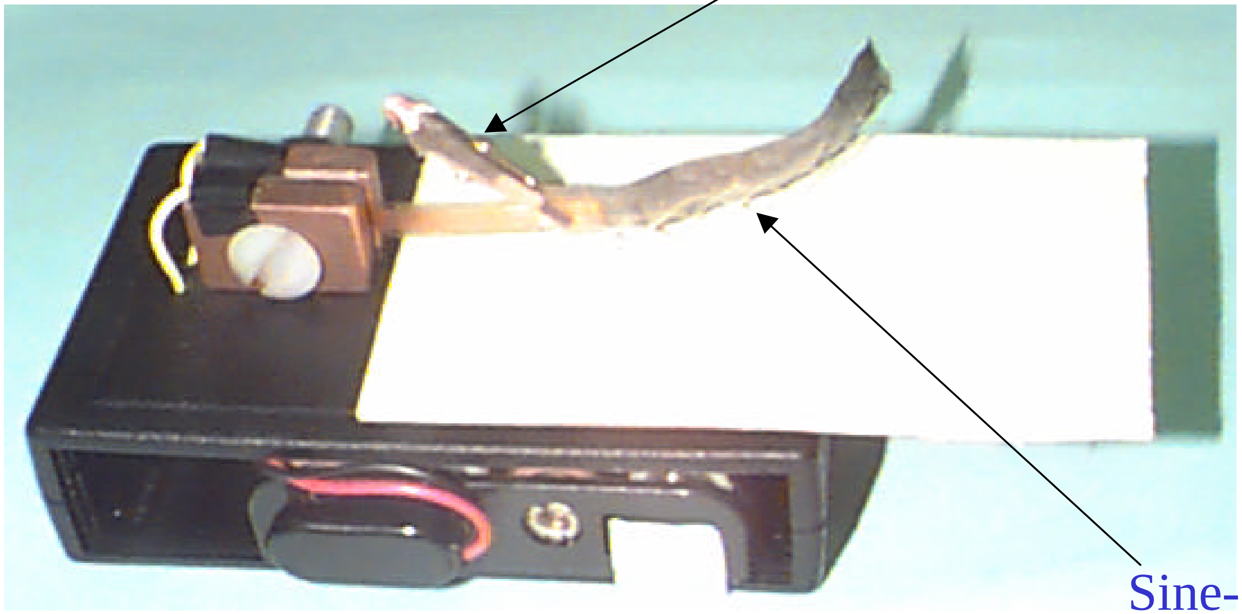
Surface Wiper Setup



Clip that clamps the electrodes strip and the ionomer



Sine-shape wire blade

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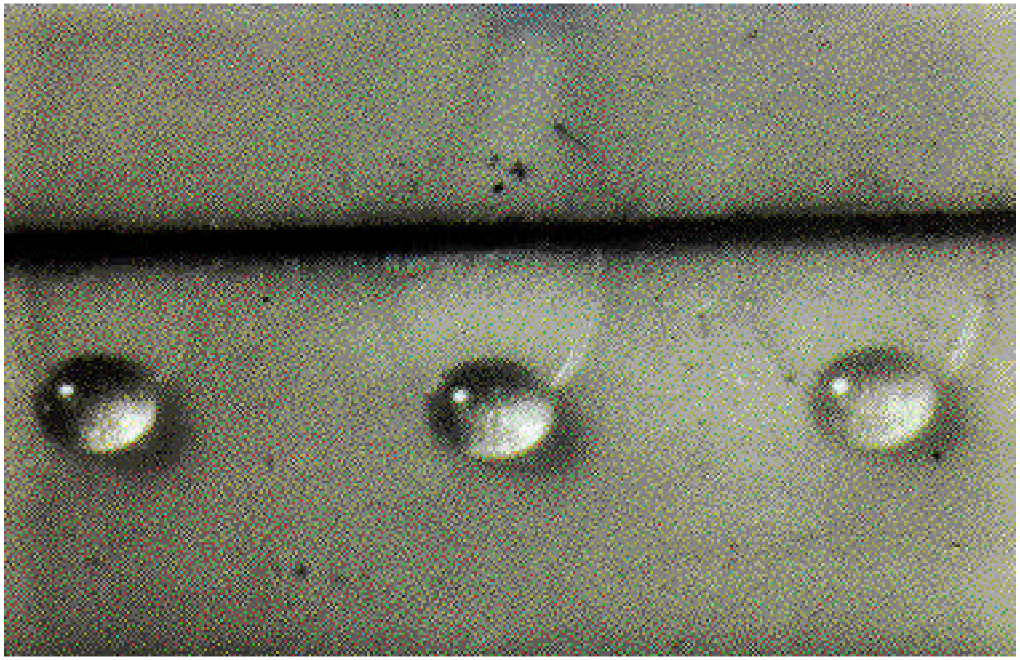
IPMC wiper processing

Inkprint bonding of the sine-shape wire blade



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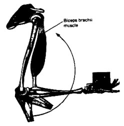
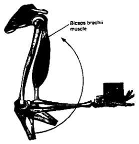


EAP BENDING ACTUATOR/SENSOR
Capabilities

- Actuator with large bending displacement
- Bending strain sensor
- Effective at low temperatures (-100^{o}C) and vacuum (1-torr)
- Unique electrical resistance that grows with decrease in temperature
- Capacitive behavior allowing power storage



SIGNIFICANT FUTURE APPLICATIONS

- EAP surface wiper for dust removal for solar cells and optical/IR windows
- Miniature robotic arm for miniature sample manipulation
- New locomotion of walking and flying insect-like robots
- New family of MEMS using EAP actuators and sensors.
- Support active/controllable inflatable structures
- Mechanisms that are driven by resilient, damage tolerant actuators

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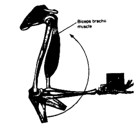
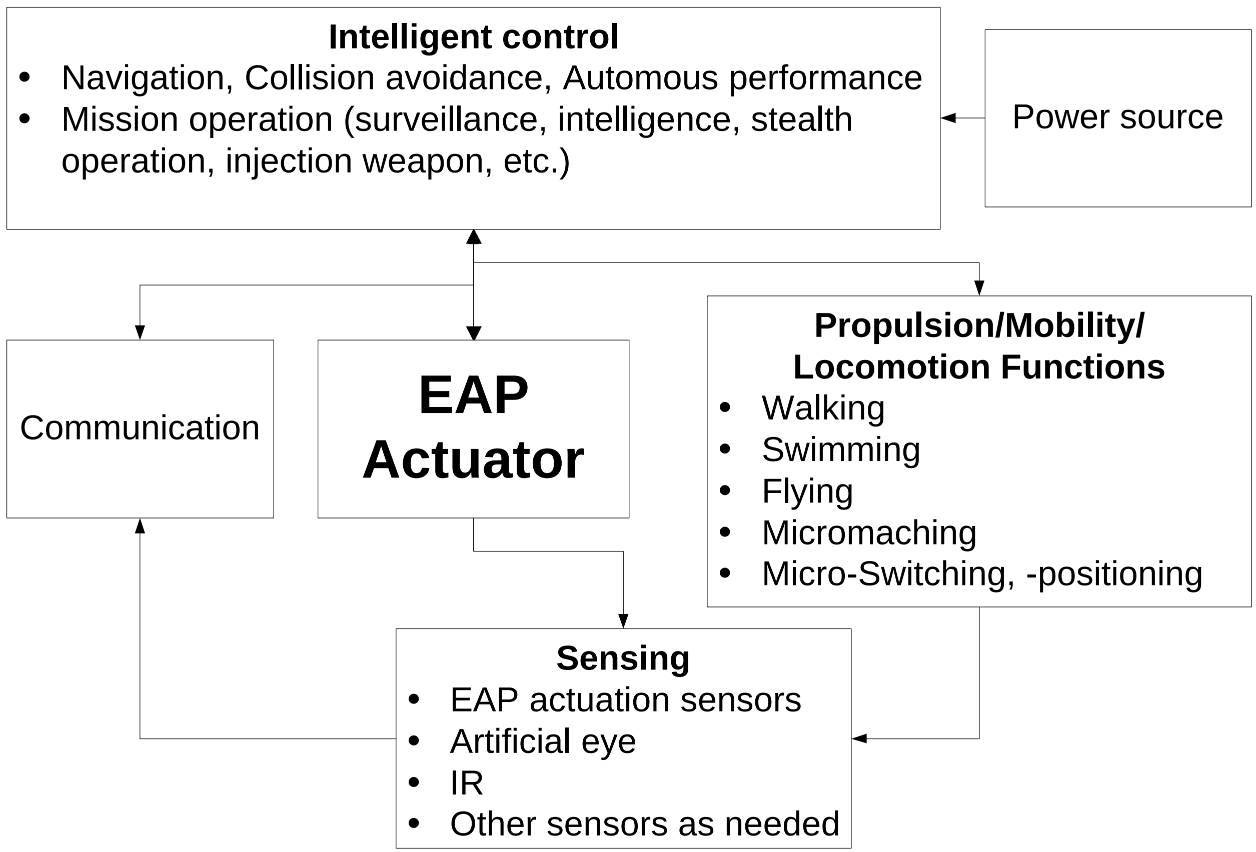


ELEMENTS OF AN EAP ACTUATED ROBOTS



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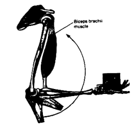
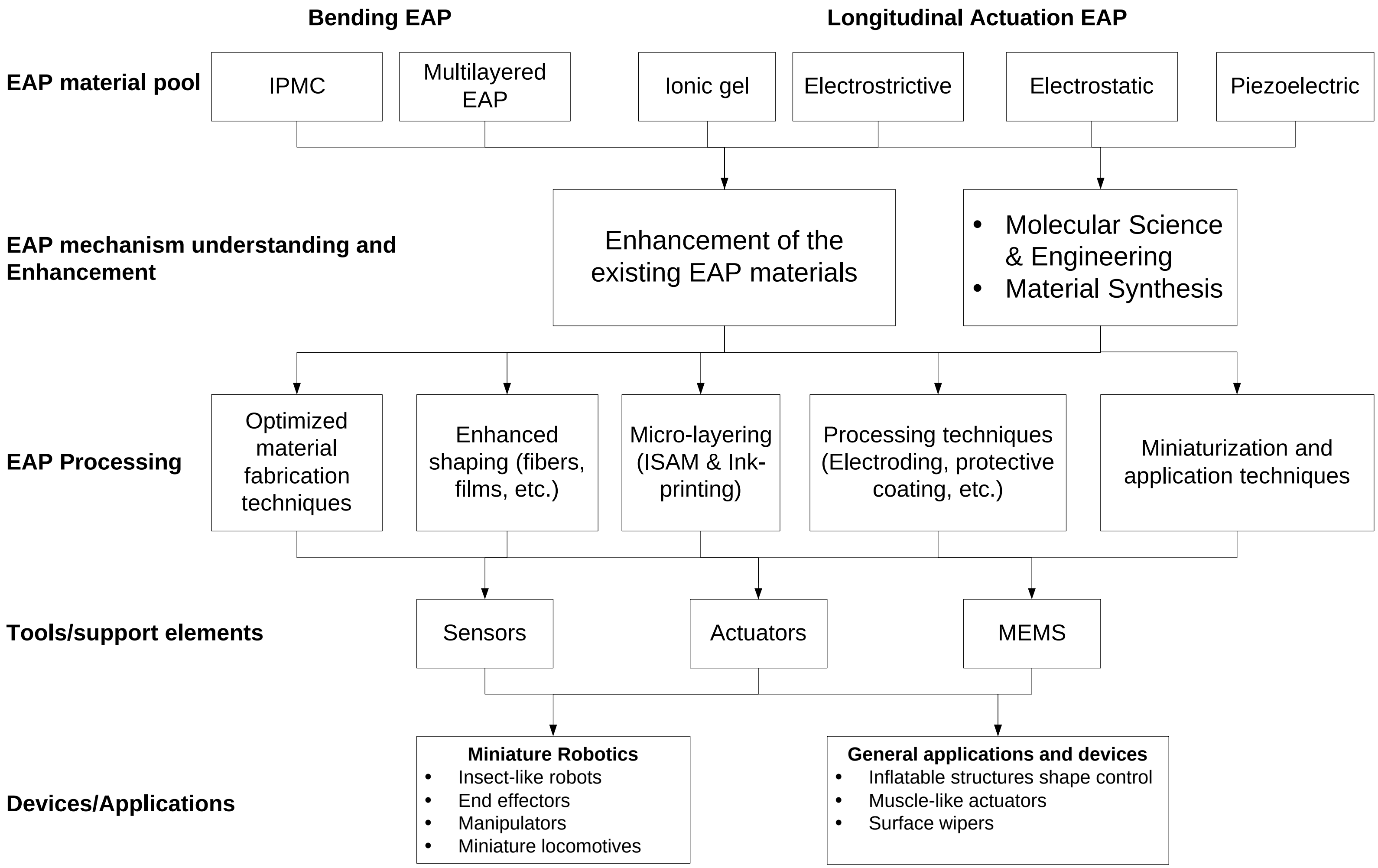


EAPAD development flow chart



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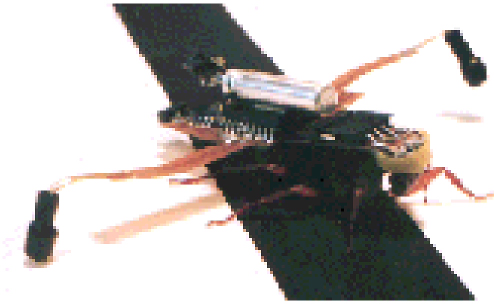
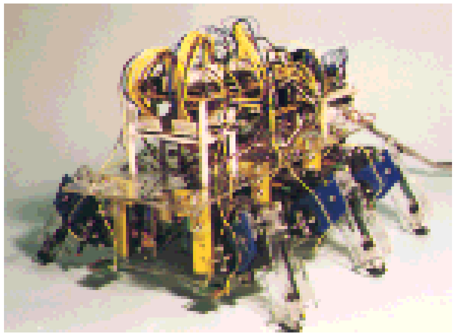
INSECTS AS WORKHORSES AND ROBOTS

- Insects were used by various researchers (e.g., University of Tokyo, Japan) as locomotives to carry backpack of wireless electronics.

- EAP offer the potential of making insect-like robot to replace the "real thing".



Cricket



Spider

Cockroach

Reference: http://www.leopard.t.u-tokyo.ac.jp/

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Models for EAP* Actuated Flexible Robots

Soft landing

SCALABLE AUTONOMOUS ROBOTS FOR COLONIZED PLANETARY EXPLORATION (SAROPE) TO PERFORM MULTI-TASKING IN-SITU MISSIONS

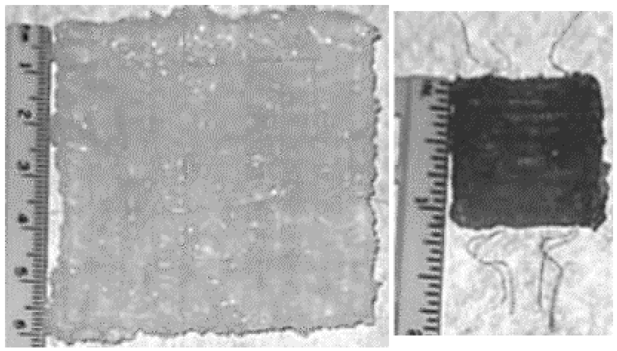
Effective locomotion: Hopping, flying, crawling and digging

Coordinated robotics

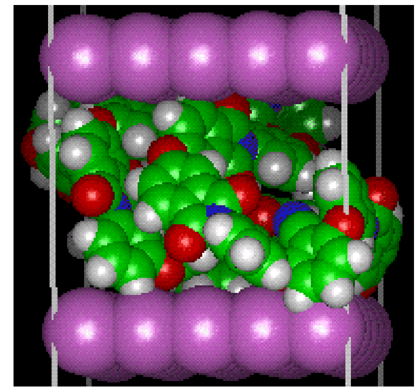
*EAP - Electroactive polymers

EAP materials and processes that are being considered

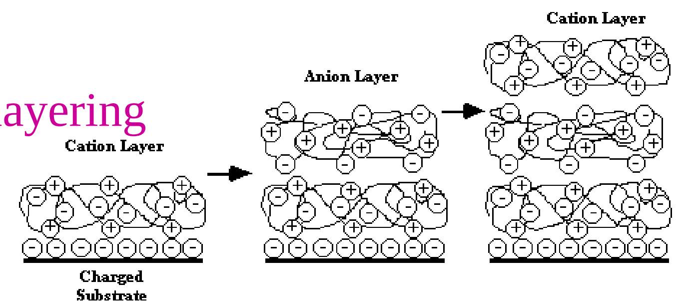
Alternative EAP:
Ionic gel EAP



Design tools:
Computational chemistry

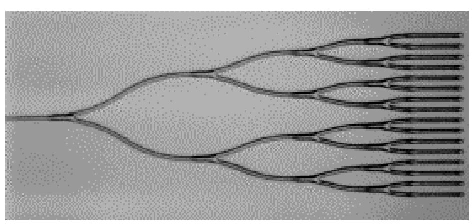


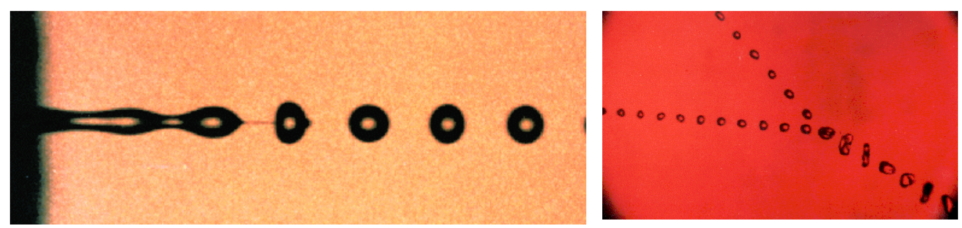
Ionic Self-Assembled mono-layering



Micro-fabrication techniques:

Ink-printing





100-µm Waveguide

50-µm drops jet

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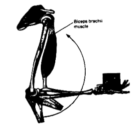
EAP as breakthrough technology

- Out of 68 candidate topics, submitted to the JPL’s ESD Director Review in April 98, 12 were selected including this EAP technology to be considered as "one of the potential breakthrough technologies, which have great promise in enabling JPL's exciting new missions through and beyond the next decade”. A presentation to Ed Stone and ESD was made on 5-8-98.

- In its August 98 Issue, Discover Magazine covered our EAP activity under the category Breakthrough Technology. The article is entitled “Bendbots”.

- The SPIE September issue of OE Reports Newsletter is dedicated to Robotics and will cover this LoMMAs task activity.



Technology implementation

- A surface wiper is scheduled for delivery to MUSES-C by 2/99
  - The ink-printing technology is expected to be used to micro-adhere the fiber blade to the bending actuator
  - A new etching process is being implemented jointly with LaRC and Integument Technologies
  - Optimization of the power drive is done at JPL
  - Issues of deformation and electrode-strip/wiper joining are being addressed
- A robotic arm is under development and prototype

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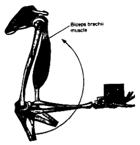

Conclusions

- Two types of EAP actuators were employed to develop components of a robotic arm emulating human hands.
  - Scrolled rope electrostatic actuator is used to lift the arm, composite rod.
  - A 4-finger IPMC gripper serves as the end-effector.

- A multi-finger gripper was demonstrated to have large finger opening/closing with a relatively large mass carrying capability.

- To address the issue of dust on Mars, a unique surface wiper that moves similar to human finger was demonstrated.
  - Wipers are designed to remove dust from optical/IR windows as well as solar cells

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